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Intensive forestry: some socioeconomic and environmental concerns

A. Carlisle and L. Chatarpaul

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Petawawa National Forestry Institute

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PETAWAWA NATIONAL FORESTRY INSTITUTE

The Petawawa National Forestry Institute (PNFI) was formed on April 1, 1979, as the result of an amalgamation of the Petawawa Forest Experiment Station with the Ottawa-based Forest Management and Forest Fire Research Institutes. The Forestry Statistics and Systems Branch was established at PNFI in 1980.

In common with the rest of the Canadian Forestry Service, the Petawawa National Forestry Institute has as its objective the promotion of better management and wiser use of Canada's forest resource to the economic and social benefit of all Canadians. Because it is a national institute, particular emphasis is placed on problems that transcend regional boundaries or that require special expertise and expensive equipment that cannot be duplicated in CFS regional establishments. Such research is often performed in close cooperation with staff of the regional centres or provincial forest services.

Research at the Institute is in two main areas:

FIRE RESEARCH AND REMOTE SENSING. Every year in Canada large areas of productive forest are destroyed by fire. Research concentrates on studies of forest fire behaviour, the development of new methods of fire control, the evaluation of fire-fighting equipment and retardants, and the development of computerized fire management systems that are rapidly finding applications with fire-fighting agencies across the country. The environmental and economic impact of forest fires and the use of fire as a silvicultural tool for intensive forest management are also studied.

In remote sensing, investigations are made into the application of modern satellite and airborne remote sensing systems to forestry problems. In this respect, the ARIES digital image analysis system is proving invaluable.

INTENSIVE FOREST MANAGEMENT. As Canada moves into more intensive management of its forest to meet expected increases in demand for this vital resource, the role of this program will become increasingly important. An extensive reforestation program will require a steady supply of high-quality seed of the desired species. Improved growing stock, obtained through tree breeding and forest genetics research, is highly desirable. Increased emphasis is being placed on using the entire above-ground portion of the tree (biomass), but the effect on the environment of this and other forms of intensive management has to be carefully monitored. Biotechnological methods of improving yield while maintaining site productivity are being investigated.

In support of its research programs, the Institute has at its disposal a 98 km^2 area of forest in the western part of the Petawawa military reserve. Records of experiments and sample plots have been maintained since the 1920s. The forest also serves as a field laboratory for students from local schools, and a visitor centre is operated during the summer months.

The operations of PNFI also include THE FORESTRY STATISTICS AND SYSTEMS BRANCH (FSSB) which is responsible for the acquisition and publication of national information on the forests of Canada. Through the Canadian Forest Inventory Committee, which is comprised of provincial and federal forestry officials, the FSSB works in close cooperation with provincial forest agencies to improve and standardize the information available on Canada's forest resources.

Through the FORSTATS program, which involves all regional establishments of the Canadian Forestry Service, the FSSB coordinates the acquisition and publication within the CFS of national statistics on the forest of Canada.

Every five years, the FSSB publishes Canada's Forest Inventory; the official report on the location, extent, species, and condition of the forest resource. In addition, the FSSB is working closely with the provinces to expand the information available on changes to the forest from fire, harvesting, insects and disease, and from forest management activities. This information is essential to the development of sound policies for the improved management of this important and renewable natural resource.

INTENSIVE FORESTRY: SOME SOCIO-ECONOMIC AND ENVIRONMENTAL CONCERNS

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Abstract

This report outlines recent changes in society's demands upon forests, shifts in public attitudes towards the forest resource, and the increasing interaction and potential conflict between these policies, socio-economic issues, and environmental concerns.

The increasing use of intensive forest management and utilization techniques, particularly the use of short rotations and whole tree harvesting, will make increasing demands on the soil. The distribution of nutrients in forests is described in relation to the individual components of nutrient flux.

It is unwise to make general, simplistic statements about the effects of any harvesting technique. Such effects are specific to site, species, and element, and are influenced by many interacting factors which can be placed in perspective only by using holistic models. The assessment as to whether or not impacts are acceptable must be considered in the context of management objectives. In the future, environmental impact assessment should be an integral part of forest management plans.

Long-term productivity cannot be attained by simply applying fertilizers to the forest soils. An understanding of physical and biological processes is the key to the development of methods for maintaining soil fertility.

Forestry schools must place greater emphasis on soil science and research into forest processes to provide the basic information needed to assess environmental effects. The report also discusses genetic and socio-economic impacts, and the suggestion is made that socio-economic rather than purely economic analyses be used in assessing forestry programs.

Résumé

Le présent rapport expose l'évolution récente des exigences de la société à l'égard des forêts, les changements d'attitude du public à l'égard des ressources forestières, et l'interaction croissante et donc la plus grande possibilité de conflits entre ces politiques, les questions socio-économiques et les préoccupations en matière d'environnement.

L'utilisation accrue de techniques intensives d'aménagement et d'exploitation des forêts, en particulier le raccourcissement des intervalles d'exploitation et l'exploitation par arbres entiers, imposera au sol des exigences croissantes. La distribution des éléments nutritifs dans la forêt est décrite par rapport aux composantes individuelles du mouvement des éléments nutritifs.

Il n'est pas sage de porter des jugements généraux, simplistes, sur les effets de techniques de récolte particulières. Ces effets sont propres à chaque site, à chaque espèce et à chaque élément, et subissent l'influence de nombreux facteurs en interaction que seule l'utilisation de modèles intégraux permet de mettre en perspective. La question de savoir si les répercussions de ces techniques sont acceptables doit être considérée dans le contexte des objectifs d'aménagement. À l'avenir, l'évaluation des répercussions sur l'environnement devrait faire partie intégrante des plans d'aménagement forestier.

Il n'est pas possible d'assurer la productivité à long terme simplement en appliquant des fertilisants sur les sols forestiers. La compréhension des processus physiques et biologiques est la clé du développement des méthodes de maintien de la fertilité du sol.

Les écoles de foresterie doivent mettre davantage l'accent sur la pédologie et sur les recherches concernant les processus forestiers afin de fournir les renseignements de base nécessaires à l'évaluation des répercussions sur l'environnement. Le rapport examine aussi les répercussions génétiques et socio-économiques de la foresterie et il propose que l'on se serve d'analyses socio-économiques plutôt que purement économiques pour évaluer les programmes forestiers.

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INTENSIVE FORESTRY: SOME SOCIO-ECONOMIC AND ENVIRONMENTAL CONCERNS

1 INTRODUCTION

The purpose of this paper is to outline recent trends in forest management and utilization, discuss current changes in attitude towards forests and forestry, examine socio-economic factors that interact with environmental problems, examine effects of forest utilization on soil fertility, define the main problems, and suggest actions for the future. The paper is based in part on a report entitled "Forest exploitation and environmental objectives" presented to the 11th Commonwealth Forestry Congress held in Trinidad in 1980. The theme of that conference was the contribution of forestry to social and economic development. The economic aspects of forestry were discussed in other papers of the Conference and will not be discussed in depth here.

1.1 Society's increasing need for forest products

In the past thirty years man has had to face the stark fact that many of the seemingly limitless natural resources such as high grade timber, high grade ores, and readily accessible oil are being rapidly depleted. Some of these resources, such as timber, are theoretically renewable, although stands of very large trees may well have gone forever. Other resources, such as minerals, are theoretically recyclable, but re-use is not always economic. Oil, coal, and natural gas, the vital sources of energy and chemicals for modern industrial society, are nonrenewable.

Somewhat belatedly, people in the developed countries have turned back the clock and are looking at renewable forests to supply not only conventional lumber and fibre for pulp, but also an array of fuels and livestock feeds. On the other hand, people of developing countries have relied upon woody vegetation for a large part of their fuel and livestock feed for centuries. Moreover, society, at least in developed countries, has a rapidly increasing need for outdoor recreation, and is demanding more access to forests for this purpose. The increased contact with the forest, and exposure to wildlife programs in the media, has resulted in increased awareness of and concern for the way forests are used. The public is demanding more involvement in the formulation of policies concerning the use, renewal, and reservation of forests and other natural resources. The increasing need for more forest products, therefore, must be considered in the context of constraints raised by public concern, which usually result in restricted utilization. Some constraints are well founded, but others are based on faulty premises. Consequently, information, interpretation, and public awareness systems are being established in many developed countries to enable the public to participate in resource use and policy development.

The current or predicted fresh water shortages throughout the world also constrain forest use. Managers of irrigation projects using large aquifers are finding that in many places (e.g. Arizona, California) water levels are falling, and increasing demands for water by industry is making fresh water one of the world's scarcer commodities. Anyone flying over thinly inhabited northern Ontario with its multitude of lakes will find it hard to believe that water is scarce, but water is not sufficient where it is needed most, near the urban centres. The increasing concern for maintaining a sustained water supply has resulted in forests being managed on water catchment areas to regulate water supply. Such policies constrain cutting, often over very large areas. For example, the setting aside of large reserved areas for parks and conservation could remove a significant portion of forest from the cutting cycle in countries such as Canada and the United States.

The overall scenario is one of an urgent need for more forest products, coupled with greater constraints on forest use by limitation of cutting for environmental, conservation, recreation, water regulation, and scientific reasons. After centuries of "mining" high grade timber, the present trend is to produce more fibre per hectare by intensive management and harvest more tree components by mechanized harvesting (Reed 1973). However, the more you take out the more you need to put in, and intensification of forestry[1] must take into account the social, economic, and environmental constraints.

1.2 Changes in attitude

Recent shifts in the attitude of society towards forests, and subtle changes in resource use philosophy are likely to have a major impact on forest management and utilization in the near future. In many forested countries of the world man has been faced with a surfeit of trees for centuries. Forests may have supplied shelter, fuel, and structural materials but they impeded farming and sometimes threatened man's survival. Excepting in some European countries, it is only recently that man has realized that forests are finite resources needing management and maintenance. Even today few people comprehend the importance of forest products in the world's economy.

The lack of concern for forests has led to low investments in management and research and development, along with a perpetuation of industry's "get in and get out" utilization philosophy. Investment by governments tends to be crisis-oriented, in response to the prediction of a major scarcity of fibre for conventional forest products and energy. Politicians, industry, and the bureaucrats have belatedly become aware of the need to invest

[1]For the purpose of our discussion intensive forestry includes such management practices as planting of superior genotypes, weed control by herbicides, fertilization, short rotations, whole tree harvesting, and other techniques aimed at rapidly increasing yield as soon as possible to supply fibre for conventional forest products as well as for energy.

money and manpower in the efficient management of forests. As Jack Westoby succinctly put it at the 8th World Forestry Congress in Jakarta, Indonesia, "Forestry yielded its time honoured place as the Cinderella sector, the sector commanding absolute posteriority."

The effects of management practices on the forest environment and forest renewal have also been largely ignored. Although foresters have been taught to take site factors into account in their planning, for the most part the edaphic effects of their actions have not been uppermost in their minds. In many countries soil science is still of minor importance in forestry education even though forest soils and tree gene pools are the ultimate forest resources. Foresters are occupied with meeting practical objectives to satisfy society's short term needs for fibre, recreation, etc. Society's needs and attitudes, however, have shifted in the past twenty years, and environmentalist groups are demanding a recognition of impacts of forestry practices, particularly in developed countries. Influenced by these pressures many more foresters are aware of the need to predict effects, and are becoming conscious of the dearth of basic information on forestry processes. All too often the response by scientists to the question of what will be the response to a particular forest treatment is, "We do not know!".

The public, particularly the vocal environmentalists, have a great antipathy towards any extensive, uniform forest operation, especially large clear-cuts and planted monocultures. As in agriculture it might be more economic in certain circumstances to grow an uniform forest product on large areas and harvest it in large quantities than to establish and harvest a diverse tree crop. Managing and harvesting plantations of several species costs more, and the extra cost will be passed on to consumers. On the other hand, large scale monocultures, particularly where there is a very narrow genetic base, involve risks of devastation by pests and diseases, and extensive clear-cuts may have adverse effects upon soils, wildlife and, in some circumstances, upon the tree gene pool. Conflicts on these points between operational foresters and environmentalists in the developed countries have often resulted in the environmentalists prevailing, mainly through political pressure. With the predicted increases in intensive forestry - which implies crop uniformity - these conflicts between environmental groups and foresters will increase unless confrontation is replaced by coopération. In North America environmental assessments are becoming an integral part of most industrial development plans and, given the will, there is no reason why such assessments should not be part of forest working plans. The environmental assessments will need to be designed to minimize the operational inertia which such assessments tend to introduce. Forestry is already plagued by inertia, and does not need more.

In some countries foresters are ecologically oriented and well aware of their stewardship responsibilities. Unfortunately,

in North America many foresters are still evolving from the harvesting-only forest engineer to the forester concerned about good management, harvesting, and regeneration on ecological principles. In the past there were such large areas of accessible, merchantable forests that management and stewardship were seldom considered.

The past two decades have seen an incursion of economists into most policy-making groups concerned with industrial and resource development - even into research - and forestry is no exception. Unfortunately, cold economic cost/benefit analysis is not amenable to forestry situations because it tends to ignore recreational, aesthetic, and environmental benefits which are not properly quantifiable. Economists tend to overlook the socio-economic impacts of their recommendations. Nevertheless, forestry operations are frequently judged only by the contribution they make to the Gross National Product and Balance of Payments. In the past few years, however, there has been an increasing distrust in such analyses of forestry policy. Economic gain is not necessarily the same as socio-economic gain, and what is good for one sector of society may not be good for another (Westoby 1979).

The inclusion of a stewardship ethic in forestry planning taking into account economic, social, and environmental needs, becomes more common every year. The fact that this was the theme of the 11th Commonwealth Forestry Conference is a symptom of the evolution of these new attitudes in forestry.

1.3 Conflicts of uses

Multiple land use is an accepted method of forest management in many countries. However, using the land for several purposes involves clearly stated objectives, assigning priorities to uses, and assessing trade-offs between uses. No matter how carefully several uses are integrated, conflict is inevitable. In a forest managed for both fibre yield and water regulation, for example, there are constraints on stocking, species, stand geometry, burning, etc. Optimizing water regulation is often at the cost of fibre yield. Recreation is often in conflict with forest use for fibre yield, as well as with environmental factors. Incidentally, the best recreation sites are often located on the more sensitive soils. These days forest managers are faced with a bewildering matrix of conflicting forest uses that cannot be easily quantified and assessed by optimization techniques.

Increased use of intensive forestry is likely to aggravate such conflicts. Short rotation systems using poplars, for example, are most productive on good farmland, and sooner or later, as demands for food increase, there is likely to be competition for land and conflict at the forestry/farm interface. Proponents of short rotation (30 years) and mini-rotation (2 to 10 years) systems are developing "agroforestry" systems whereby widely spaced, fast growing trees are interplanted with agricultural crops until the tree canopy closes. The economics of

this approach is still in question, but a socio-economic analysis may present agroforestry systems in a more favourable light than a conventional cost/benefit analysis in strictly dollar terms. Successful systems of farm woodlots are well established in many countries, providing the farmer with fuel, a supplementary income, and greater self-sufficiency. Tension at the forestry/agriculture interface could be overcome by integration of short rotation systems into agriculture, rather than by confrontation.

Another serious potential conflict is the competition for wood fibre between forest industries (lumber, pulp, etc.) using conventional forest products and the proposed use of huge amounts of fibre for liquid fuels and other forms of energy. World shortages of fibre for conventional forest products have been predicted and proposals to use wood fibre on a large scale for alcohols, gas, and solid fuel may create competing demands. Use of low grade forests (low grade to foresters but not necessarily to environmentalists) for fuels and the removal of branches, leaves, and even stumps during harvesting of better quality forests to provide fibre for energy are both technically feasible, but may well conflict with environmental objectives. Considering public pressures, the priority these environmental objectives receive in management plans may be higher than most foresters and economists anticipate. It is likely that social and environmental concerns rather than economics will decide whether or not forests are used for energy.

Extensive use of forest fibre for liquid fuels for transportation in north temperate countries is not likely until problems of engine design, phase separation of alcohol/gasoline blends, and storage and distribution systems have been overcome. This is not likely to occur before the end of the century. Use of alcohols made from sugar cane and alcohol/gasoline blends for transportation is apparently successful and rapidly expanding in the warm climate of Brazil. In the Brazilian situation, however, phase separation, cold starting, and cold running problems are less severe than in cooler climates and the existing storage and supply infrastructures not so well established as the massive systems of North America and Europe (Adams 1979, Berger 1979, Gratch 1979). Although there may be delays in alcohol use in north temperate countries, extensive use of renewable forests for this purpose may well occur if society rejects the use of coal and natural gas to manufacture alcohols and gasoline. There is increasing recognition among the public that coal and natural gas are non-renewable and that there is a potential danger of increasing carbon dioxide emissions, with predicted major effects on climate. Use of forests for energy in addition to firewood must be accepted as a possibility and the associated conflicts taken into account in planning.

2 INTENSIFICATION OF FOREST MANAGEMENT AND UTILIZATION

Intensive forest management has been used for many years in countries such as Germany, Britain, France, Italy, Sweden, and Finland where indigenous forests have either disappeared or have low productivity. Plantation management systems in these countries are well developed and include such refinements as use of genetically superior stock. The foresters are highly trained in management and utilization. Countries with more extensive natural forests have removed the best timber and are making inroads into species which, in the lumbering heyday, were regarded as weeds. The United States is passing from the exploitation phase to the management phase, as reflected by the increasing area of intensively managed pine plantations. New Zealand has greatly expanded its fast growing Pinus radiata plantations to provide urgently needed fibre, and there is increasing interest in selecting and breeding fast growing species and genotypes to shorten rotations and produce more fibre per hectare. Species such as poplars (Populus spp. and hybrids), sycamores (Acer spp.), larch (Larix spp. and hybrids), ash (Fraxinus spp.) and willows (Salix spp.) are being selected, grown, and tested for high yields. However, countries with huge forest resources, such as Canada, are relative latecomers to the intensive management scene and forestry is at the early stage of evolution from exploitation to management. Canada, the Soviet Union, and Brazil still possess huge resources of timber in remote places far from mills and other conversion centres. The urgent need is to grow fibre nearer the mills in order to reduce transportation costs which follow escalating oil costs. In the past five years there has been a tremendous surge of interest in Canada in growing trees such as poplars on abandoned farmland, and intensifying forest management as a whole (Reed 1973, Raitanen 1978).

The differences in yield between intensively managed forest and natural forest are sometimes spectacular. For example, in Canada the natural forest produces on average less than 1 tonne ha^{-1} yr^{-1} of wood fibre. In contrast, hybrid poplar plantations can produce up to 16 o.d. tonnes ha^{-1}, sycamores (Platanus occidentalis) up to 19 o.d. tonnes ha^{-1}, and red alder (Alnus rubra) up to 15 o.d. tonnes ha^{-1} (Raitanen 1978, Ek and Dawson 1976, Belanger and Sancier 1975, Steinbeck and May 1971, De Bell et al. 1978, Carlisle and Methven 1979). However, it costs much more to produce stock, cultivate, control weeds, plant, fertilize, and maintain mini-rotation poplar plantations than to manage a natural forest. Further information is needed on the economics of these mini-rotation systems (Pfeiffer 1979).

Natural forests of the north temperate zone generally have low yields, with some exceptions such as red alder (Alnus rubra) on fertile sites. Nature is more concerned with survival than high fibre yields. These low yields, as well as high wages, increase harvesting and transportation costs, making it difficult for forest industries in developed countries to compete in the world's market.

Northern foresters look with envy and anxiety at the seemingly ideal growth conditions in tropical areas. Estimates of net primary production in the tropics average about 2 400 g m^{-2} yr^{-1} (Murphy 1975, Lugo et al. 1973) with a maximum of 3 210 g m^{-2} yr^{-1} in Sarawak (Murphy 1975), while temperate forests average about 1 300 g m^{-2} yr^{-1} and boreal forests only 800 g m^{-2} yr^{-1}. Some authors such as Westlake (1963) give even higher values (2 600 to 5 200 g m^{-2} yr^{-1}) for productivity of tropical forests. These raw figures might lead us to conclude that tropical rainforests are perfect for the production of low cost timber. But Jordan (1979) and other authors (eg., Whitmore 1975, Kato et al. 1974) caution us. Jordan points out that while net primary production of natural tropical forests is undoubtedly higher than in temperate zones, this is due to higher leaf production and not to significantly higher wood production (Table 1).

Tropical soils are frequently of low fertility and some, like those of central and eastern Amazonia, are virtually oligotrophic and very sensitive to disturbance. The lack of seasonality also permits pests and diseases to proliferate. The forest survives these attacks because of its great species and genetic diversity. Monocultures of species such as Pinus caribaea have been established in Venezuela, Puerto Rico, and Brazil on sensitive, tropical soils of low fertility and yields appear to be good (e.g., wood production 8 to 10 tonnes ha^{-1} yr^{-1}), but no information is yet available about effects on the soil, effects of pests and diseases, or second generation productivity. 'Ecologists watch these developments with interest. Such major projects as the developments in Brazil involve thousands of imported workers and the sociological implications are massive.

Foresters of the temperate zone, therefore, need not envy their tropical colleagues. Temperate soils are less sensitive than those in the tropics, and the seasonality, with cold winters, exercises some degree of control of pests and disease. Foresters in temperate zones have a great opportunity to increase yields, subject of course to environmental, economic, and social constraints.

Intensification of forestry has caused a trend towards shorter rotations and harvesting of more tree components. The shorter rotations mean frequent site disturbance and harvesting of smaller and more juvenile material with higher proportions of bark and higher nutrient concentrations. Harvesting stems, branches, twigs, and leaves removes more elements and carbon from the site than conventional roundwood harvest. The tempo of forestry has changed from the slow, complex plant succession in the unmanaged natural forest, with survival the top priority, to intensive management in pursuit of larger quantities per unit area of more uniform fibre products in as short a time as possible, with monetary profit the top priority.

In natural forest the forester could afford to be conservative and concentrate on his logging schedules. In the future, foresters will need to be on their toes and look beyond simplistic logging and regeneration if the productivity of inherently unstable intensive forest systems is to be maintained. In this intensive forestry context environmental conservation issues will need to be foremost in foresters' minds when they make their plans.

3 ENVIRONMENTAL EFFECTS

In this section we concentrate on the impact of forest utilization on soil fertility, with some mention of other factors.

3.1 The nutrient budget

Unless the forest is a closed, steady state system (which exists only in theory), soil nutrients enter the system, circulate within it, and exit from it. The nutrient budget for a natural forest undisturbed by man can be expressed as a simple model:

$$\Delta E_{p+s} = E_R + E_M - E_L \pm E_G - E_F - E_E$$

where ΔE_{p+s} = annual change (+ or -) in the quantity of nutrient E in the vegetation and soil of the ecosystem.

$+E_R$ = annual income in precipitation + aerosols.

$+E_M$ = annual income in mineral weathering.

$-E_L$ = annual losses by soil leaching (exit in stream waters).

$\pm E_G$ = annual gains or losses by gaseous exchange (e.g. losses of oxides of nitrogen, gains from nitrogen fixation if E is nitrogen).

$-E_F$ = losses by fire.

$-E_E$ = losses in sediments by erosion.

Insect attacks are not included as these redistribute nutrients and do not necessarily mean a net nutrient loss from the system.

In forests where intensive management follows harvesting, more factors, such as loss due to harvesting ($-E_H$) and income from chemical fertilizers ($+E_C$), enter the picture. Time also becomes important. Nutrients lost from the system by harvesting at time t_1 have to be replaced before the next harvest at time t_2 if the nutrient capital is to be maintained. Assuming one fire per rotation, and one initial dressing of fertilizer, the model changes to:

$$\sum_{t_1}^{t_2} \Delta E_{p+s} = - E_H + \sum_{t_1}^{t_2} E_R + \sum_{t_1}^{t_2} E_M - \sum_{t_1}^{t_2} E_L \pm \sum_{t_1}^{t_2} E_G - E_F - \sum_{t_1}^{t_2} E_E + E_C$$

Rotation length ($t_2 - t_1$) is obviously a major determinant of nutrient gain or loss over the rotation. Harvest (E_H), fire (E_F), and fertilization (E_C) are not annually supplemented in this model. The significance of annual income of elements in rainfall, snowfall, and aerosols (E_R), mineral weathering (E_M), leaching losses (E_L), and gaseous flux (E_G) is very much affected by rotation length. Harvest loss (E_H) is a one-shot affair in the rotation unless the forest is thinned, but because of its magnitude it is a major determinant in the nutrient budget. The same applies to fire.

The adoption of short rotations (shortening $t_2 - t_1$) and whole tree harvesting (increasing E_H), therefore, greatly affect nutrient balance. Ideally, whole tree harvesting should be followed by a long rotation to give the nutrient capital time to be replenished. Use of both whole tree harvest and short rotations greatly accentuates nutrient loss.

3.2 Nutrient capital

The nutrient capital is what the forester has to work with. Table 2 (after Pritchett 1979) gives a crude idea of total nutrient content in boreal and tropical ecosystems. Phosphorus levels are comparable but quantities of other elements vary greatly. It is interesting to note that in the tropical moist forest most of the phosphorus and potassium is in the vegetation which can be removed by harvesting. Also, complete removal of living biomass from the boreal sites would deprive the soil of about 45% of the calcium. However, much of the total nutrient capital may not be available to the vegetation, like money locked in a vault to which there is very limited access. Total nutrient capital is, therefore, a maximum value and can be misleading. The part of the capital available to vegetation is what is really important, and it is difficult to measure. The significance of nutrient gain or loss expressed as a proportion of the total capital may be doubtful but it is the best guide we have in most cases.

The amount of a nutrient lost in harvesting is the sum of the products of biomass and nutrient concentration for each tree component harvested. Generally speaking, nutrient concentrations in bark, branches, and leaves are several times greater than that in the stemwood (e.g., Table 3). Because young trees have a high proportion of bark, branches, and leaves, their mean concentrations are higher than for older trees. It follows, therefore, that intensive, high yielding forest systems using whole tree harvest and short rotations, with their high biomasses, high concentrations, and short recovery times, will place a major strain on soil nutrient resources.

Tables 4 and 5 give the distribution of nitrogen in temperate and tropical forests. The situation for phosphorus and the bases will be very different from nitrogen, and little data are available for micronutrient distribution.

3.3 Nutrient income

Nutrients such as nitrogen, phosphorus, and the bases enter forest ecosystems in precipitation, aerosols, dust, mineral weathering, N_2-fixation, and through the mobile fauna. In most studies of nutrient income in precipitation the rainwater, snow, aerosols, and dust are grouped together. Estimates may well be low, particularly for oceanic climates, where aerosols containing the bases impact on tree surfaces in rainfree periods and later wash down in the throughfall, without being recorded in the incident rain. Mineral weathering and nitrogen-fixation will be considered in some detail because of their importance. Nutrient income and loss in wildlife and insect flux tend to cancel each other and will not be considered in this report.

The input of elements from natural sources is, except for N_2-fixation, beyond the control of the forester. He can, of course, introduce N_2-fixing plants or encourage free-living organisms to fix more nitrogen by providing a better substrate as an energy source and modifying soil pH. Nevertheless, these sources of "free fertilizer" must be taken into account as the principal credits appearing annually on the nutrient balance sheet.

The lowering of rain pH due to industrial emissions of oxides of nitrogen and sulphur and its effect on forests is beyond the scope of this paper. Readers are referred to the literature, particularly research in Norway (Abrahamsen et al. 1976, Denison et al. 1976, Rennie 1978, Overrein 1976). It suffices to say that acid rain is an important factor in the interaction between society and the forest environment. A tree cover may tend to buffer the rainfall as it passes over the canopy, but there is likely to be a lowering of pH in many forest soils with low buffering capacity, with far-reaching effects on soil microorganism activity and ion exchange capacity, both key factors in forest soil dynamics. Whether this problem should be approached politically, or technologically, is a point in question.

Nutrient income in precipitation

Rainfall, snowfall, aerosols, and dust in the atmosphere all contain micronutrient elements and, although the yearly income may sometimes be small, over long rotations such as 100 years the nutrients from this source are a vital part of forest dynamics and soil nutrient capital renewal.

Rainfall and Snowfall. Income is variable depending upon the quantity of precipitation and the vicinity of element sources such as oceans and industrial emissions. Table 6 gives a few examples for North America. Nitrogen income is usually about 5 kg ha^{-1}

yr^{-1} with some very high values (e.g. 41.4 kg ha^{-1} yr^{-1}) in polluted areas. Calcium income is about 6 kg ha^{-1} yr^{-1}, ranging from 0.9 to 23.5 kg ha^{-1} yr^{-1}. There is less potassium; about 2.5 kg ha^{-1} yr^{-1} (0.9 to 5.6 kg ha^{-1} yr^{-1}). Over 100 years, therefore, about 500 kg ha^{-1} of nitrogen, 600 kg ha^{-1} of calcium, and 250 kg ha^{-1} of potassium enter the systems in this way. These quantities are substantial. Reliable data for phosphorus are scarce. Phosphorus is present in very low concentrations in rainfall; microorganism activity in the collecting vessels makes it difficult to assess income.

Aerosols. Estimates of nutrient income in aerosols (separate from rainfall and snowfall) are few, but Mayer and Ulrich (1974) obtained aerosol data for a beech stand in central Germany and Miller and his colleagues (1976) studied a coastal stand of Corsican pine in Scotland (Table 7) (Miller 1979). From this data it is apparent that the income of bases in aerosols (which are usually omitted from forest nutrient budgets) can be of the same order as or greater than income from rainfall in both the oceanic climate of Scotland and the continental climate of central Germany.

Income by nitrogen fixation

Nitrogen enters forest ecosystems by biological fixation of molecular nitrogen by free-living organisms (such as bacteria and blue green algae) and symbioses between N_2-fixing microorganisms and higher plants, both legumes and non-legumes. In these symbioses the microorganism is supplied with energy to fix molecular nitrogen by the host plant. The reduction of molecular nitrogen (N_2) to ammonia (NH_3) by the enzyme nitrogenase requires a lot of energy.

Rates of income of fixed nitrogen vary among ecosystems and species. At present we know more about N_2-fixation in agriculture than we do in forestry, but the discovery of the acetylene reduction technique to measure nitrogenase activity has made estimation of N_2-fixation rates considerably easier. Table 8 gives an idea of the rates of N_2-fixation by different ecosystems and species (after Fortin et al. 1979).

Agricultural rates of N_2-fixation are high (10 to 300 kg ha^{-1} yr^{-1}), particularly for legumes. N_2-fixation by forests (0.4 to 300.0 kg ha^{-1} yr^{-1}) is variable, but estimates are few and more data are needed to get a true picture. Alders (Alnus spp.) can fix nitrogen (12 to 300 kg ha^{-1} yr^{-1}) as rapidly as legumes (47 to 300 kg ha^{-1} yr^{-1}). It is only recently that the alder symbiosis has been understood and the endophyte (Frankia) identified. When problems of endophyte isolation and culture have been overcome it will be possible to select endophyte genotypes with superior N_2-fixing ability.

In recent years there has been an increase of interest in the potential of using N_2-fixation as a forest management tool to maintain soil fertility, increase yield, and reduce reliance on

costly, energy-demanding nitrogen fertilizers. Our understanding of the role of N_2-fixation in forest dynamics is increasing, and it is now clear that N_2-fixing organisms are active not only in the soil but in decaying logs and the phyllosphere. For example, microorganisms in the Douglas-fir (Pseudotsuga menziesii) phyllosphere fix nitrogen at a rate of 7 to 23 kg ha^{-1} yr^{-1} (Burns and Hardy 1975). Jones (1976) observed that nitrogen fixing microorganisms are present on the leaves of many tree species, both conifers and hardwoods, in Britain. For example, Jones (1970) calculated that from 53.6 to 119.5 g ha^{-1} day^{-1} of nitrogen were fixed in the Douglas-fir phyllosphere during the growing season. Even decaying logs of trees such as chestnut (Castanea) are the site of N_2-fixing activity (0.9 kg ha^{-1} yr^{-1}) (Cornaby and Wade 1973). Lichens, such as Peltigera, Stereocaulon, Colleme, and Nephroma spp., contain algae such as Nostoc sp. and Stigenema sp. which fix nitrogen at a rate of 26 to 310 mg cm^{-2} hr^{-1} (Henriksson 1971). Granhall and Linberg (1978) report that microorganisms in the litter layer ("field and bottom layer and other litter") of Sphagnum communities in conifer forests in Sweden fix as much as 37 kg ha^{-1} yr^{-1} annually.

It is now apparent that N_2-fixation occurs at many loci throughout the forests of the world. N_2-fixing symbioses of trees, ground vegetation, and lichens; free-living bacteria and blue green algae in the soil and on rotting wood; microorganisms intimately associated with the rhizosphere; and microorganisms on leaf surfaces of trees and ground flora, are all fixing inert molecular nitrogen into a form that vegetation can use. Most estimates of N_2-fixation in the forest are probably low, because not all the loci of activity have yet been identified and examined. It is likely that in the future N_2-fixation will play a more prominent role in forest management, and certainly it will receive more attention as a nitrogen input in studies of nitrogen flux in forests.

Income from mineral weathering

Release of minerals from weathering of rocks within the ecosystem has been the least known part of all nutrient budgets and cycles. Recently, however, soil scientists such as Pritchett (1979), and Clayton (1979), and ecologists such as Marchand (1971), Frederiksen (1972), Cleaves (1970, 1974), Likens (1977), and Woodwell and Whittaker (1967) have started to shed light on the subject. The research has taken two approaches, the Weathering Rind approach and the Mass Balance approach.

Weathering of exposed rocks, boulders, etc., forms a rind of weathered rock used by geologists for dating purposes and more recently by soil scientists to study nutrient release. Granitic stones on Colorado glaciers have rinds 15 mm thick after 5 000 years and 45 mm thick after 15 000 to 20 000 years, so weathering is a slow process (Birkeland 1973, 1974). Volcanic rocks weather 0.01 to 0.1 times more slowly than coarse plutonic rocks (Colman 1977). During weathering, elements are released. For example, biotite is hydrolized and releases iron and magnesium, oxidises

ferrous to ferric iron, and releases potassium. Using the Weathering Rind approach Clayton (1979) computed nutrient release for several minerals (Table 9) in a young soil containing fresh gravel. Potential element yields are considerable, far more than falls annually in the precipitation.

The Mass Balance method has been used in watershed (e.g. Marchand 1971, Frederiksen 1972, Cleaves et al. 1970, 1974, Likens et al. 1977) and lysimeter (Woodwell and Whittaker 1967) studies. Nutrient impacts and losses, as well as biomass accrual or loss and soil aggradation, are computed for the system and a mass balance equation solved for the elements (Clayton 1979). For example, annual calcium release by weathering processes is calculated using the equation

$$Ca_{rw} = (Ca\ efflux - Ca\ influx\ (ppt)) + \Delta C_{p+s}$$

where

Ca_{rw} = annual calcium release from weathering.

Ca efflux = annual calcium loss in stream water.

Ca influx (ppt) = annual influx in precipitation.

ΔCa_{p+s} = annual net change in calcium accumulation in plants and soil.

The income from weathering of several minerals has been computed using this approach (Table 10). In many cases, potassium and calcium income from weathering appears to be of the same order as that from precipitation (Table 6).

A word of caution. The weathering rind gives an idea only of elements released from exposed rocks, i.e. in this case from young soils with fresh gravel. Release levels may be very different for older soils with rocks well covered. Also, the fact that the elements are released does not necessarily mean that they are available to the vegetation.

The mass balance approach is reliable if release is computed just from annual efflux and influx, as these can both be measured with some precision. When the annual net change of an element in plants and soil is included, however, this means estimating element levels at two points in time. The variance of each estimate may be considerable, reducing reliability of the release estimate unless net changes in plants and soil are large. It first provides orders of magnitude. Further research is urgently needed in this area to supply data for modelling the effects of forest practices on nutrient flux.

Table 11 summarizes the quantities of elements entering forest ecosystems from several sources. It gives foresters some

idea of the magnitude of these credits in the nutrient flux balance sheet. These fluxes cannot be ignored.

3.4 Nutrient loss

Loss by harvesting

Conventional roundwood harvest only removes the stems of merchantable size, compared with harvest of the total tree above ground and whole tree harvest including roots. Tables 4 and 5 indicate that the proportion of nitrogen, for example, in the stems varies greatly with species and age (e.g. 36-year Douglas-fir 43%, 16-year loblolly pine 50%, 34-year red alder 71%, 3-year sycamore 29%, and 1-year hybrid poplar 33%). Concentrations may be low in stemwood, but biomass is high. The biomass of leaves is very low, but the high concentrations of elements frequently result in leaves containing more nitrogen than stems (e.g., Scots pine, white spruce, Cryptomeria japonica). Harvesting stems, leaves, and branches greatly increases nutrient egress compared with stem harvest. For example, from Table 4;

	Stem	Stem + Branch + Leaf	Increase %
	Nitrogen kg ha^{-1}		
Douglas-fir	125	288	130
loblolly pine	115	231	101
red alder	309	432	40
sycamore	15	52	247

In the case of hardwoods such as alder, poplar, and sycamore it may not be advantageous to harvest the deciduous leaves. For example, if 1-year-old poplar were harvested with their leaves attached, the nitrogen output would be 192 kg ha^{-1}, whereas the N output would be 78 kg ha^{-1} if the trees were harvested without their leaves. The same applies to sycamore (Table 4) which has most of its nitrogen in its leaves. Therefore, cutting after leaf fall greatly reduces nitrogen loss.

Harvesting roots with stump pullers is being considered by some managers attempting to get the most fibre from their forest for energy and other purposes. This greatly increases nitrogen loss. For example (Table 4), the roots of 55-year Scots pine contain 184 kg ha^{-1} of nitrogen, compared with 88 kg ha^{-1} in the stem and 269 kg ha^{-1} in the stem, branches, and leaves. Harvesting the roots, stem, branches, and leaves would entail a nitrogen egress of 453 kg ha^{-1}, 417% more than a stem harvest, and 68% more than harvesting stem, branch, and leaf. Before stump and root pulling is undertaken on a large scale it is recommended that not only the effect on nutrient loss be considered, but also the overall effect of mineral soil exposure.

Tropical forests, especially complex rain forest, are a very different situation from temperate forests because woody creepers and leaves sometimes make it difficult to distinguish between tree components such as stem and branch. In Table 5 it can be seen

that most of the available potassium and calcium are in the vegetation and litter layers. This is indicative of the sensitivity of these forests to extensive cutting. Tables 4 and 5 show the variability of nutrients in stems, roots, branches, leaves, litter, soil, etc., and how difficult it is to make any general statement on nutrient egress for different harvesting intensities.

The soil nutrient data are difficult to evaluate. In the literature, some nutrient capitals are given as totals and some as available or exchangeable. Firstly, the soil nutrient capital is greatly affected by the depth to which soil is sampled and, although "sampled to rooting depth" is a common criterion, it is frequently arbitrary. Rooting depth of what? Trees or all vegetation? Also, the techniques for assessing availability to the forest vegetation of nutrient elements in forest soils are not reliable and were designed for agriculture. Forest soil science is a long way behind agriculture, and soil dynamics are often the weakest link in models designed to assess impacts.

Leaching losses

Water moving down the soil profile of a forest carries with it both cations and anions which, unless intercepted, end up in the stream flow and are lost from the system. Investigation of these losses has produced results that are variable even for undisturbed sites. On disturbed sites the variation is even more pronounced.

Nitrogen losses have been studied most intensively, and Vitousek and Melillo (1979) summarize the present state of knowledge based on results from 18 temperate forest catchments. Losses of NO_3-nitrogen range from 0.05 to 4.5 kg ha^{-1} yr^{-1} on pristine sites and, on disturbed sites subjected to different levels of cutting, from 0.6 to 125.5 kg ha^{-1} yr^{-1}. The very high level of 125.5 kg ha^{-1} yr^{-1} was observed by Likens et al. (1970) when vegetation was removed from the Hubbard Brook catchment. The reason for the loss is not fully understood, and several hypotheses have been proposed to explain it. In general, it appears that disturbance of the forest increases nitrogen mineralization and reduces uptake of nitrogen by the plants, at least for a short time. Mineralized nitrogen in excess of plant uptake can be lost by leaching from the soil to the streams, as gases by ammonia volatilization, or by exit of nitrogen and its oxides through denitrification. On the other hand, mineralized nitrogen can be retained within the system via uptake by microorganisms involved in organic matter decomposition, fixation of ammonium ions on clay surfaces, nitrate absorption on soil colloids, and by drought (Vitousek and Melillo 1979). However, it is apparent that in some circumstances nitrogen loss by leaching can be equal to or considerably more than nitrogen income in precipitation (Tables 9 and 11) and, if the forest is disturbed by cutting, can be equal to or more than denitrification losses.

Denitrification losses

Little information is available on gaseous nitrogen losses due to denitrification, but Todd, Waide, and Cornaby (1975) state that for a deciduous forest ecosystem in the southeastern United States it is potentially in the order of 10 to 18 kg ha^{-1} yr^{-1}. In this ecosystem, gaseous loss was about the same as income from nitrogen fixation (12 kg ha^{-1} yr^{-1}). Todd stated that the two processes cannot be considered independently; together with nitrification they represent a tight nutrient cycle. In the U.S. southeast about 140 kg ha^{-1} yr^{-1} of nitrogen are cycled annually, so N_2-fixation and denitrification each account for about 10% of this total. It is of interest to note that N_2O emissions from denitrification increase with fertilization. This gas is suspected of promoting the degradation of the ozone layer which protects man from excessive radiation (Delwiche et al. 1978). Doubtless foresters and agriculturists will hear more about this in the future.

Losses due to fire

Effects of fire on the soil can be short-term or long-term. There is much information available about the former and very little about the latter. The reader is referred to the review by Raison (1979) for details. Effects depend upon the fuel type, fire type, frequency of fire, and the ecological situation. The precise effects upon the soil of heat, ash, and microclimate modification associated with fire have not been determined even for one community according to Raison (1979).

The ash which falls to the soil surface is rich in bases (e.g. 0.3 to 19.1% K, 0.5 to 34.9% Ca, 0.7 to 15.4% Mg) and low in nitrogen (0.03 to 1.8%) and phosphorus (0.0004 to 3.1%). The pH of the ash is, as one would expect, very high (e.g. 6.3 to 12.4) (Raison 1979). The effects of this sudden influx of bases is sure to affect soil processes profoundly, as many microorganisms are sensitive to pH. Nitrogen is oxidized during fire and much is lost as gases. Bases are also lost as convective ash from the system. The quantities of elements lost and deposited as ash vary tremendously with fire and fuel types. Raison (1979) states that deposits of 26 kg ha^{-1} P, 190 kg ha^{-1} Mg, 751 kg ha^{-1} K, and 1582 kg ha^{-1} Ca are fairly typical when felled tropical forests are burned. Partly ashed residues may increase levels of C and N in the soil.

How fire effects the nutirent budget depends upon site, soil, and climate. If rainfall is high, the soil well drained, and the cation exchange capacity low, major losses of bases can be expected by leaching. In dry areas, leaching will be less. Ash on steep slopes will be redistributed or washed into water courses and lost if there is heavy rainfall. Effects of fire on nutrient cycles will be greatest when most of the ecosystem nutrients are in the vegetation and duff, or where nitrogen is in short supply. However, one cannot generalize, and each fire and each site must be considered separately for nutrient budget purposes.

3.5 Effects of intensive management and intensive harvesting on nutrient budgets

The details about nutrient captial, income, and loss are given in the preceding pages to show their great variability. It is also clear that when assessing effects of harvesting on nutrient balance (loss or gain) it is not enough to simply assess nutrient loss in the extracted fibre, and compare it with nutrient income from precipitation and the nutrient capital, as many non-ecologists do. There are other sources of appreciable nutrient income and loss. Some processes, especially nitrogen fixation and denitrification, are sensitive to soil pH and other characteristics, and vary enormously from one site to another. It is just not possible to generalize about impacts of different management harvesting techniques. The proliferation of factors make it more profitable to take the holistic approach and develop models designed to assess effects of changing different parameters for specific situations. Effects are site and element specific. Fortunately the factors involved, and the types of information needed to make the models work, are known. Unfortunately, forest soil science is so far behind agricultural soil science that much of the process data we currently rely upon is for agricultural situations. There are serious gaps in our knowledge about nutrient availability, nitrogen fixation, denitrification-nitrification processes, soil microorganism activity, and other forest soil processes. It is also necessary for foresters to look beyond the crude nutrient budget. Losses may appear small compared with the system's nutrient capital, but may be large in relation to the part of that capital actively involved in cycling and forest dynamics.

We still tend to resort to the "black box" approach, knowing what goes in and what comes out of the forest, knowing very little about what happens in between. One difficulty is that it is often hard to define exactly what we want to know. The effect of forest management on what parameter? On soil fertility? What do we mean by 'fertile'? Fertile relative to what? Should we aim at maintaining the soil productivity status quo so that the soil can support a similar forest after cutting? Or should we upgrade soil productivity to support a different kind of forest with higher yields than before? Also, how do we decide a management technique is good or bad? If a harvest removes more of an element than enters the system before the next harvest, how much of a loss can we accept? Or should we adopt the attitude that any net loss is bad stewardship? If so, what do we do about it?

The answer to most of these questions lies in management objectives. Provided these objectives include an environmental component, it is for the manager to decide what kind of a forest he wants, what effects he can accept, and how much he can spend to remedy any adverse situation. It would be as well if the forester were to align his environmental objectives with those of society, or he can expect conflict and further management constraints. The manager should also understand basic ecological principles or be prepared to listen to people who do.

Nutrients have been the focus of attention for many years, but losses of fibre mean losses of carbon from the system, and soil disturbance also reduces soil organic matter levels. Soil organic matter is vital to the well being of forests, and gaps in our knowledge of the carbon cycle are sure to receive more attention. Global losses of soil organic matter, particularly from areas of intensive agriculture, make a significant contribution to the increasing carbon dioxide levels in the atmosphere with their potential effects upon 'climate. If forest soils lose organic matter on a large scale, the effects on carbon dioxide levels in the atmosphere could be considerable.

The most detailed information available about nutrient flux in response to different forest management practices refers mainly to broad-leaved forests of the temperate zone. These forests, however, are growing on relatively fertile soils, compared with the infertile forest soils of the boreal zone. What we urgently need to investigate are the effects of management upon such sensitive soil types.

Whenever man takes something out of the forest, puts something into it, tramples the soil, or compacts it with machinery there will be an effect. We can guess at some effects, but little is known about others. Some effects may be of little or only ephemeral importance, but others could have major consequences. Understanding these effects is a major challenge to forest scientists, who, with the support of managers, could provide the basic information required to ensure that our forests are left to future generations in as good or better a state as they are today.

3.6 Replacement of nutrient losses

If it has been shown that nutrients are being lost from a system at a rate that is not acceptable to the manager, or undesirable changes in pH, ion exchange capacity, or organic matter levels are taking place, the problem is what to do about it. Many foresters tend to take a simplistic attitude towards nutrient lossses and say, "We can easily replace the losses with fertilizers," which is not necessarily correct. For fertilization to be effective it must be of the right kind, in the right quantity, and added at the right time. Even when all these conditions are met, if the soil does not possess the ion exchange capacity to hold ions in the system, there will be considerable fertilizer nutrient loss. In addition, exit of ions such as nitrate could cause stream water pollution problems. Quite apart from these problems is the overriding problem of fertilizer availability and cost in terms of money and energy. Nitrogen fertilizer made via Haber-Bosch's process requires a lot of process energy, and agriculture is competing for these fertilizers which become scarcer every year. World shortages of phosphorus fertilizers have been predicted, so foresters might well find it difficult to replace nitrogen and phosphorus loss by fertilizers in the future. The bases pose less of a problem; calcium for example can be added in limestone

dressing but, again, there are the costs of transportation and application.

In recent years there has been an increase in interest in maintaining forest soil fertility by biological means. Nitrogen fixation, for example, by legumes and non-leguminous symbioses, can add nitrogen to the soil at a rate far in excess of income in precipitation. Free living nitrogen-fixing bacteria and blue green algae in the soil have a limited supply of energy and fix relatively small amounts. It is becoming apparent, however, that nitrogen is fixed in many niches in the forest ecosystem, for example by lichens, on leaves, on decaying logs, and in the rhizosphere of vegetation, quite apart from root-microorganism symbioses (Fortin 1979). When these nitrogen sources are added up, they make a considerable annual contribution of nitrogen. Nitrogen fixation can be encouraged by inoculation and provision of favourable substrates for microorganism activity once more is known about the processes and organisms involved. Non-leguminous tree and shrub N_2-fixing symbioses such as alder (Alnus sp.) can be used to boost nitrogen income and provide soil organic matter, although problems of competition and control still remain unsolved.

In short- or mini-rotation systems the relatively heavy nutrient losses that occur resemble those of agriculture. It may be necessary to use agricultural techniques to maintain soil fertility, such as growing legumes on the site before, during, or after planting to maintain nitrogen and soil organic matter levels, as well as increasing ion exchange capacity. Foresters may have to consider the possibility of alternate cropping of conifers and hardwoods. For example, the effects of aspen (Populus spp.) on the soil, when this hardwood is permitted to remain on the site between pine rotations or mixed with pines (Pinus spp.), are likely to be beneficial. Under such circumstances there are increased inputs of readily decomposable organic matter which releases nutrients as well as improving ion exchange capacity. The whole concept of growing trees in mixtures designed to produce fibre and maintain soil fertility at the same time needs examination.

Foresters will also want their trees to make the best use of available nutrients. Trees better able than others to take up nutrients can be selected and bred, but the trees will need other desirable characteristics such as good growth, form, pest resistance, and hardiness. This multiple trait breeding is no simple matter. Nutrient uptake can benefit from mycorrhizal associations. Mycorrhizae can increase the uptake of phosphorus, when it is in a relatively unavailable form, by the fungi acting as root extensions with much greater surface areas capable of steepening the phosphore diffusion gradients. Could this process be exploited to improve efficiency? There are many biological tools the forester can use to reduce fertilizer needs. Before he can do this, however, we need to know much more about soil processes and the microorganisms involved.

Foresters will have to accept that maintaining soil fertility by biological means involves an economic price. Low value hardwoods alternated with valuable conifers, or sites left for a few years under alfalfa between mini-rotation crops of trees, may result in a temporary loss of fibre yield. However, improved soil fertility could make up for this loss in the long term. In his cost-benefit analyses the forester will need to look beyond revenue from fibre, and include soil productivity gains.

4 GENETIC EFFECTS

Intensive forest management and intensive utilization both affect the genetic constitution of the forest. The trend towards using selected superior trees or breeding new genotypes for use in plantations means that new genetic types are being introduced to sites of former natural forests. These new types may hybridize with local natural species, a possibly deleterious development. If natural genotypes are of value, steps will need to be taken to preserve their genetic integrity by confining planting to selected local genotypes.

The use of genetically superior clones is increasing in intensive hardwood forestry, and tissue culture techniques may one day permit the use of conifer clones. The danger with a clonal forest is that it may not have the variability and flexibility to cope with pests and diseases, or with the extremes of climate experienced over a rotation. Foresters will need the guidance of geneticists to avoid using too narrow a genetic base.

Forest harvesting also has potentially harmful effects. In many parts of the world the natural forests have been high-graded by selective cutting of those trees with best growth and form. Growth rate is controlled by many genes and it takes a high degree of selection to shift the population means of the trees' growth characteristics. The impact of high-grading on a population depends upon the size of the population and its variability. Extensive clear-cutting and concentration of cutting on individual valuable species is likely to have a greater effect on the genetic constitution of populations than high-grading. Already many valuable tree species in both temperate and tropical zones are in danger of genetic degradation. A forester needs to take into account maintenance of gene diversity and genetic integrity in his management plans as part of good stewardship.

The increasing use of introduced tree species has brought its own problems of pest-host interaction. Native trees may not be adapted to resist introduced pests and diseases. On the other hand, the introduced species may be sensitive to indigenous pests and diseases.

5 SOCIO-ECONOMIC EFFECTS

The production, sale, and manufacture of wood products generates money and employment. The socioeconomic effect of this activity is far-reaching. An emphasis on intensive forestry will increase mechanization of management and harvesting, decreasing employment in the primary resource sector. Conversely, there may be an increase in employment in secondary industries concerned with the manufacture of fibre-based commodities. Intensive forestry is expensive, and we can expect an increase in costs of producing fibre which will be passed on to manufacturers and, ultimately, the public. Market forces will ultimately govern the acceptability of such price changes. Increased production of renewable wood fibre which can be used for many purposes is more likely to benefit society if manufactured in the country of origin, takes into account environmental effects, and does not conflict excessively with other social needs such as food and water. Also, it is important that benefits are passed on to society either directly or indirectly.

Increased harvesting and export may increase industrial profits, enhance the gross national product, improve the balance of payments, and be of true economic benefit. This does not necessarily mean that there will be an increase in the prosperity and well being of the people. The apparent paradox is illustrated by Westoby's (1979) description of the effects of the tropical hardwood industry. Between 1950 and 1976 the cutting of tropical hardwoods quadrupled and annual exports of logs from relatively poor countries of the tropics to the affluent nations rose from 3 million m^3 to 40 million m^3, providing considerable revenue to source countries. At the same time processing of logs in the countries of origin declined, depriving source countries of $2 billion or more and several hundred thousand person-years of employment (Pringle 1976).

Forest industry development in less developed countries is often foreign-controlled and largely export oriented. Frequently, exploitation is uncontrolled and management minimal, with "marginal farmers, shifting cultivators and landless poor" following in the wake of loggers (Westoby 1979). Over one-half the original moist tropical forest has disappeared from Africa, one-third from Latin America, and over two-fifths from Asia according to Sommer (1976) and Westoby (1979). There may be short-term economic gains from this tropical hardwood exploitation but relatively little gets put back into forestry or channelled to improve the conditions of the people of source countries. As Westoby (1979) says, referring to the tropics, "In precious few countries have the energies of the foresters been bent upon helping the peasant to develop the kind of forestry that would serve his material welfare." There are, of course, exceptions but poor people in many countries continue to have a desperate need for fuel, building materials, cheap furniture, and paper in spite of increased harvests. The costly fibre-based products imported into the source countries from affluent countries are beyond the

means of most citizens. To a much lesser extent the situation occurs even in trade between the affluent nations, although the latter nations are better able to afford highly priced imported manufactured goods, and divert some of the profits from forest exploitation into forest renewal, management, and research.

Use of forests for energy (liquid fuels, gas, etc.) could be of great benefit to some isolated communities where fossil fuel and electricity costs are high. Trees used for energy can be of any form, so there could well be a shift from using only forests with trees of good stem form to including crooked, scrubby materials. This could mean that degraded forests and scrub forests of all kinds might become grist for the energy mill. Under the circumstances conservation problems are sure to crop up. Some forests of ecological interest have survived only because their poor form deterred logging.

There will be tremendous pressure on forests, especially in the tropics, if wood is used extensively to produce fuel for transportation, and stationary engines. The political and socio-economic impacts will be far-reaching. Forests will face great dangers of degradation.

6 CONCLUSIONS

1. The world needs more renwable wood fibre, more recreational facilities in forests, more parks and wildlife and forest reserves, large volumes of biomass for liquid fuel production, cattle feed, and chemicals, and large expanses of forest for watershed protection. Some uses are conflicting. For example, a situation is developing where society requires more wood products but, due to other uses of forest and the opinion of an environmentally-conscious public, foresters can cut less. The clear consequence is increased pressure on the forest resource, and on foresters.

2. Yield from natural forests is often low, and attempts are being made to develop high yield forestry systems using superior genotypes, intensive management, mechanization, whole tree harvest, and short rotations. These systems, while potentially very productive, make greater demands on the soil. Environmental considerations will probably dictate the extent to which these intensive techniques can be used, and environmental impact assessment should be a part of forest management plans. Current knowledge of forest soil processes and current crude nutrient balance assessment techniques are not adequate to meet future needs of environmental impact assessment.

3. In the past, economic evaluations of forestry have been mainly economic rather than socio-economic. There is a trend towards taking social issues into account in forestry planning, but so far this has had little impact, particularly

in the tropics. There is a need for foresters to plan and assess management and utilization in socio-economic terms so that more segments of society benefit from forestry activities.

4. In spite of high primary productivity, many tropical forests are sensitive to vegetation removal, burning, and other forms of disturbance. The disturbance of these forests and their extensive conversion to high yielding monocultures could have serious long-term consequences. There is an urgent need to assess the effect of such conversion on long term site productivity.

5. Replacement of nutrient losses by fertilizers is costly in terms of energy and money, and often wasteful due to massive leaching of soluble elements into watercourses. Biological techniques should be developed to maintain soil fertility. Use of nitrogen fixation, alternate cropping, use of tree and shrub mixtures, and encouragement of mycorrhizae all have potential.

6. If foresters are to manage their forests to meet the needs of society and take into account environmental effects, forestry schools will need to provide better education in the principles of forest soil science and forest ecology, and give higher priority to forest soils research.

7. It is not possible to say whether, in general, short rotations and whole tree harvest are either harmless or harmful. Effects of rotation and different harvesting intensities on nutrient levels are site, species. and element specific. The factors involved are highly variable.

8. Holistic forest management models are urgently needed. Such models should take into account all components of nutrient income and egress, effective nutrient capital, the carbon cycle, decomposition and cycling rates, and effects on organic matter levels, ion exchange capacity, and other soil characteristics.

9. There is a scarcity of reliable information on forest soil decomposition processes, nitrification, denitrification, nitrogen fixation, and microorganism activity in most parts of the world, particularly in the tropics. This information is needed to make the management models effective.

10. We need to develop a forest stewardship ethic as a basis for developing management principles and objectives that satisfy society's need for fibre, maintain the biological productivity and potential of the soil, maintain the genetic integrity of the forest vegetation and associated wildlife, and make forest management and utilization socio-economically viable.

7 LITERATURE CITED

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APPENDIX

Table 1. Mean wood and litter production of broadleaved species in five latitudinal zones (tonnes ha^{-1} yr^{-1})

Zone	Wood	Litter	Total	Source
Northern	4.20	4.10	8.30	Timmer (1981), Alban et al. 1978
Temperate	6.58	3.28	9.86	Jordan (1979)
South temperate	6.10	3.67	9.77	"
Sub-tropical	7.58	6.44	14.02	"
Tropical	7.34	9.57	16.91	"

Table 2. Distribution of nutrients in forest ecosystems (after Pritchett 1979) (Figures in parenthesis = % of total)

Nutrient content	Living biomass		Forest floor		Mineral soil		Total
			(kg ha^{-1})				
			BOREAL FOREST (Mean of 8 types)				
N	252	(10%)	699	(28%)	1556	(62%)	2507.0
P	25	(8%)	76	(25%)	200	(66%)	301.0
K	124	(25%)	271	(54%)	106	(21%)	501.0
Ca	216	(47%)	160	(35%)	85	(18%)	461.0
			TROPICAL MOIST FOREST				
N	2016	(30%)	35	(0.5%)	4592*	(69%)	6643.0
P	241	(88%)	1.5	(0.5%)	33	(12%)	275.5
K	4598	(89%)	25	(0.5%)	508	(10%)	5131.0
Ca	4702	(20%)	132	(0.5%)	8582*	(80%)	23416.0

*N and Ca values from a Colombian caetinga forest are much lower. See Table 5.

Table 3. Concentration of N, P, and Ca in hardwood components sampled in July/August (after Carlisle and Methven 1979)

Species	Stem wood	Stem bark	Branches	Leaves& twigs	Stem wood	Stem bark	Branches	Leaves& twigs	Stem wood	Stem bark	Branches	Leaves& twigs
	Nitrogen % O.D.				Phosphorus % O.D.				Calcium % O.D.			
Maple[1]	0.06	0.42	0.16	1.05	0.006	0.02	0.02	0.16	0.30	2.98	0.48	0.94
Birch[2]	0.07	0.29	0.18	1.17	0.005	0.02	0.02	0.09	0.29	1.69	0.68	0.67
Aspen[3]	0.07	0.33	0.14	1.49	0.004	0.05	0.02	0.01	0.88	1.07	0.68	0.90
Oak[4]	0.11	0.37	0.26	1.42	0.004	0.02	0.06	0.10	0.10	2.43	0.69	0.18

[1]*Acer saccharum*; [2]*Betula papyrifera*; [3]*Populus tremuloides*; [4]*Quercus*.

Aged 40-70 years.

Table 4. Distribution of nitrogen in temperate forest ecosystems (N kg ha^{-1})[1] (Carlisle and Methven 1979)

		Age (yr)	Stems (+ bark)	Branches (+ bark)	Roots	Leaves	Soil total	Litter	Total	Author
Douglas-fir	(*Pseudotsuga menziesii*)	36	125	61	32	102	2809	175	3304	Cole 1967
Ponderosa pine	(*Pinus ponderosa*)	50	194	95	37	109	3540	413	1202	Welch and Klemmedson 1975
Red pine	(*Pinus resinosa*)	39	155	60	75	131	2750	538	--	Alban et al. 1978
Scots pine	(*Pinus sylvestris*)	55	88	57	184	124	--	409	--	Ovington 1962
Jack pine	(*Pinus banksiana*)	40	118	76	37	65	2312	689	3297	Alban et al. 1978
Loblolly pine	(*Pinus taeda*)	16	115	34	64	82	1753	307	--	Wells and Jorgensen 1975
White spruce	(*Picea glauca*)	40	102	127	67	153	2542	752	3743	Alban et al. 1978
Cryptomeria	(*Cryptomeria japonica*)	55	161	41	112	170	6900	92	--	Harada 1972
Red alder	(*Alnus rubra*)	34	309	23	176	100	5450	877	6935	Turner and Singer 1976
Sycamore	(*Platanus occidentalis*)	3	15	5	--	32	--	--	--	Wood et al. 1977
Hybrid poplar	(*Populus* x)	40	199	82	89	87	2542	752	3751	Alban et al. 1977, 1978
Hybrid poplar	(*Populus* x)	1	78	--	43	114	--	--	--	Frison 1967
Beech	(*Fagus sylvatica*)	90	290	660	150	100	7800	86	--	Nihlgard 1972

[1]Ground vegetation N content omitted as small.
Compiled from authors' basic data and converted to common units.

Table 5. Distribution of macronutrient elements in tropical forests (kg ha^{-1})

Forest type		Top total	Leaves	Roots	Other vegetation	Soil in root zone[3]	L+F+H+ dead wood
					NITROGEN		
Colombia	Primary forest[1]	741	--	--	--	5350[3]	672
"	Secondary forest[2]	713	--	--	--	6640[3]	332
Ghana	Secondary forest[2]	1283	480	324	170	4592[4]	265
Colombia	Caetinga[5]	336	72	834	--	785	132
					PHOSPHORUS		
Colombia	Primary forest[1]	27	--	--	--	254[3]	18
"	Secondary forest[1]	55	--	--	--	222[3]	12
Ghana	Secondary forest[2]	84	32	23	7	13[4]	20
					POTASSIUM		
Colombia	Primary forest[1]	227	--	--	--	119[4]	32
"	Secondary forest[2]	496	--	--	--	98[4]	21
Ghana	Secondary forest[2]	656	194	142	62	650[4]	46
					CALCIUM		
Colombia	Primary forest[1]	432	--	--	--	31[4]	94
"	Secondary forest[2]	558	--	--	--	79[4]	106
Ghana	Secondary forest[2]	1564	485	258	280	2576[4]	45
Colombia	Caetinga[5]	239	17	224	--	195	67

[1]Folster et al. 1976; [2]Greenland and Kowal 1960; [3]Soil total values; [4]Available/exchangeable; [5]Herrera and Jordan 1981.
Compiled from authors' basic data and converted to common units.

Table 6. Element income in precipitation[1] (kg ha^{-1} yr^{-1})

Location	N	P	K	Ca	Reference
U.S.A.					
Maine	1.9 - 2.5	2.9	2.9	13.0	Pearson et al. 1971
Massachussets	2.2 - 2.3	--	2.0 - 5.6	2.9 - 4.9	Pearson et al. 1971
New Hampshire	3.8 - 7.4	--	0.6 - 2.5	1.6 - 3.0	Likens et al. 1971
New York State	7.2 - 9.4	--	3.6 - 3.9	9.9 - 23.5	Pearson et al. 1971
Connecticut	2.5	--	1.6	4.9	Pearson et al. 1971
Ohio	12.0	--	0.9	0.1	Carroll 1962
Virginia	3.0	--	1.1	7.5	Fisher et al. 1968
Pennsylvania	--	--	1.0	5.6	Carroll 1962
North Carolina	3.1 - 4.4	--	1.6 - 3.3	6.0 - 9.5	Fisher et al. 1968
Florida	3.0	--	1.8	6.0	Carroll 1962
Washington	5.3	--	12.0	--	Carroll 1962
California	5.7	--	2.7	0.9	Carroll 1962
Texas	3.1	--	1.2	--	Carroll 1962
CANADA					
Lake Superior	6.8	0.2	1.6	4.0	Andren et al. 1977
Lake Huron	8.7	0.2	5.4	7.0	Andren et al. 1977
Ontario	3.0 - 41.4	0.2 - 1.2	1.0 - 10.1	2.8 - 16.0	Sanderson 1977; Wiebe 1974; Jeffries 1978;
Nova Scotia	3.9	--	--	--	Schindler 1976

[1]Compiled from authors' data and units converted. Refers to bulk precipitation.

Table 7. Inputs of bases in rainwater and aerosols (after Miller 1979)

	Ca	K	Mg
	kg ha^{-1} $year^{-1}$		
Germany (beech)[1]			
Rainwater	13	4	3
Aerosols	6	5	1
Scotland (Corsican pine)[2,3]			
Rainwater	3	3	3
Aerosols	4	7	2

[1]Mayer and Ulrich 1974.
[2]Miller, Cooper and Miller 1976.
[3]*Pinus nigra* var. *calabrica*.

Table 8. Nitrogen fixation by different plants and ecosystems (mainly after Fortin et al. 1979)

	Author	N-fixation kg $ha^{-1}yr^{-1}$
TEMPERATE FOREST TYPES		
Douglas-fir	Cromach in Todd et al. 1978; Burns and Hardy 1975; Jones in Todd et al. 1978	12-58
Mixed conifers	Todd et al. 1978	12.5
Black spruce[1]	Brouzes et al. 1969	1.5
Norway spruce[2]	Granhall and Lindberg 1978	0.4
Scots pine[3]/Norway spruce	Granhall and Lindberg 1978	3.2
Beech[4]	Burns and Hardy 1975	0.4
Alder[5]	Bond 1967; Burns and Hardy 1975; Wollumn and Davey 1973; Fortin 1979	12-300
Mixed hardwood	Todd et al. 1978	12-14
Oak, hickory	Todd et al. 1978	12
AGRICULTURE		
Soybean	Burns and Hardy 1975 in Fortin 1979	91-94
Ground nuts	Burns and Hardy 1975 in Fortin 1979	47-91
Peas, lentils, vetch	Burns and Hardy 1975 in Fortin 1979	85
Alfalfa	Burns and Hardy 1975 in Fortin 1979	128-300
Lupin	Burns and Hardy 1975 in Fortin 1979	150
Prairie	Burns and Hardy 1975 in Fortin 1979	15
Rice paddy	Burns and Hardy 1975 in Fortin 1979	10-55
TROPICAL FOREST		
Rainforest (S. America)	Todd et al. 1978	14-88

[1]*Picea mariana*; [2]*Picea abies*; [3]*Pinus sylvestris*; [4]*Fagus* spp.; [5]*Alnus* spp.

Table 9. Elemental yield from minerals (using weathering data from Berkeland 1974, and Clayton 1979) (Gross estimates)

Element	Mineral	Weathering yield kg ha^{-1} yr^{-1}
Na	Plagioclase	52
K	Biotite Feldspar	23
Ca	Plagioclase	26
Mg	Biotite	10
Fe	Biotite	11

Table 10. Elemental release from rock weathering using mass balance techniques (after Clayton 1979)

Location	Rock type	K	Ca	Mg	Reference
		kg ha^{-1} yr^{-1} released			
White Mountains, California	Dolomite	4	86	32	Marchand (1971)
White Mountains, California	Ademellite	8.0	17.0	2	Marchand (1971)
Cascades, Oregon	Tuffs/ Breccias	1.6	47	11.6	Frederiksen (1972)
Luxemburg	Metashale	0.2	8.7	15.7	Verstraten (1977)
Piedmont, Md.	Schist	2.3	1.3	1.7	Cleaves et al. (1974)
Piedmont, Md.	Serpentinite	tr	tr	34.1	Cleaves et al. (1974)
Hubbard Brook	Moraine/Gneiss	7.1	21.1	3.5	Likens et al. (1977)
Brookhaven, N.Y.	Outwash Sands	11.1	24.2	8.4	Woodwell and Whittaker (1967)
Range	--	tr-11.1	tr-86	2-52	--

Table 11. Summary of income of nutrient to forest ecosystems (kg ha^{-1} yr^{-1})

	N	P	K	Ca
Precipitation[1]	1.9-41.4 (mean c. 5.0)	0.1-2.9[3] (mean c. 1.0)	0.6-12.0 (mean c. 2.5)	0.9-23.5 (mean c. 6.0)
Mineral weathering[2]	--	--	tr - 11.1	tr - 96
N-fixation	0-300[4] (mean c. 12-20)	--	--	--
Aerosols[5]	?	?	5-7	4-6

[1]Aerosols only partly included. In some areas aerosol nutients are as great as precipitation nutrients. Data refer to North America.
[2]Data from mass balance techniques used in temperate forests.
[3]Estimates of phosphorus levels in precipitation usually low due to technical difficulties in collection.
[4]The high value is for Alnus spp. Temperate forest ecosystems fix about 12 to 20 kg ha^{-1} $year^{-1}$ (Todd et al. 1978). (See Table 8).
[5]Data for two sites only, central Germany and Scotland.